USEFULNESS OF RESERVOIRS TO AGRICULTURE IN THE IRRIGATED REGIONS.

MESSAGE

FROM THE

PRESIDENT OF THE UNITED STATES,

TRANSMITTING,

IN RESPONSE TO RESOLUTION OF THE SENATE OF FEBRUARY 8, 1899, THE REPORT OF THE SECRETARY OF AGRICULTURE, REGARDING THE USEFULNESS OF RESERVOIRS TO AGRICULTURE IN THE IRRIGATED REGIONS OF THE UNITED STATES.

FEBRUARY 18, 1899.—Read, referred to the Committee on Irrigation and Reclamation of Arid Lands, and ordered to be printed.

To the Senate:

I transmit herewith the response of the Secretary of Agriculture to the resolution of the Senate of February 8, 1899, calling for information in his possession regarding the practical usefulness of reservoirs to agriculture in the irrigated region of the United States, especially as affecting the distribution of water to crops, the area and value of reclaimed land, and the stability and profitableness of farming where irrigation is practiced.

WILLIAM MCKINLEY.

EXECUTIVE MANSION,
Washington, February 18, 1899.

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF THE SECRETARY,
Washington, D. C., February 15, 1899.

SIR: In response to the resolution passed February 8, 1899, requesting me to furnish, for the use of the Senate, such information as I might possess "regarding the practical usefulness of reservoirs to agriculture in the irrigated region of the United States, especially as affecting the distribution of water to crops, the area and value of reclaimed land, and the stability and profitableness of farming where irrigation is practiced," I have the honor to transmit herewith a brief statement furnished in accordance with my instructions by the Director of the Office of Experiment Stations, who is charged with the supervision of the irrigation

investigations conducted by this Department. While this statement contains a number of facts which have a direct bearing on the usefulness of reservoirs in the irrigated region, it shows that the available information on this subject is by far too limited. The Department is now undertaking a series of investigations on the duty of water, which it is hoped will throw much light on this and other problems connected with the successful practice of irrigated agriculture, and I shall hope hereafter to be able to publish more complete and satisfactory information on the utility of storage reservoirs than it is possible for me to give at present.

I have the honor to be, sir, your obedient servant,

JAMES WILSON, *Secretary.*

The PRESIDENT.

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., February 15, 1899.

SIR: In accordance with your instructions, I have the honor to submit herewith a statement giving a summary of the information which this office possesses regarding the practical usefulness of reservoirs to agriculture in the irrigated region of the United States, especially as affecting the distribution of water to crops, the area and value of reclaimed land, and the stability and profitableness of farming where irrigation is practiced. The statement has been prepared under my supervision by Prof. Elwood Mead, state engineer of Wyoming, who has for some time been aiding this office in connection with the irrigation investigations in my charge and is thoroughly familiar with the problems of irrigation in the West and with the literature relating thereto. While the information herewith submitted clearly indicates the practical usefulness of storage reservoirs in the equable distribution of irrigation waters at the times when they are needed for growing crops, it also shows very well the need of more definite and complete investigations of the problems of the water supply and distribution in the irrigated region of this country. Before the questions relating to the most economic utilization in agriculture of the water from streams and reservoirs can be definitely answered there must be much investigation relative to the needs of different crops for irrigation and the area of land which an acre-foot or other definite unit of volume will irrigate.

A study of the literature of irrigation in this country shows a surprising lack of information on these points. So long as our development was confined to the reclamation of small areas and the construction of works requiring little scientific knowledge in their planning and of small cost, the necessity for more definite information was not generally realized; but we have about reached the end of reclamation of land by such methods. The future extension of reclamation must largely depend on the construction of large and costly works and the storage of waters which now run to waste during the winter and spring floods. To secure the best results a knowledge of the duty of water is indispensable. We need to know what can be done with water which a reservoir will hold before we can estimate its value or determine whether its construction will pay. The builders of canals need this information in order to intelligently plan the dimensions of their works or fix the price of water rights. Farmers need this knowledge in the making of water-right contracts and in the securing of rights in streams.

In fact, more exact knowledge of the volume of water required at different times must be had before our irrigation system can have a scientific basis for its development.

This department is now organizing a series of investigations on the duty of water, and if funds are supplied to conduct them on a sufficiently large scale it is believed that ere long we will be able to give much more satisfactory replies to inquiries of this kind.

Respectfully,

A. C. TRUE, *Director.*

Hon. JAMES WILSON,
Secretary of Agriculture.

THE USEFULNESS OF STORAGE RESERVOIRS TO AGRICULTURE IN THE IRRIGATED REGION OF THE UNITED STATES.

It is the weakest link which measures the strength of a chain; so in the use of rivers in irrigation, it is not their flood volume, but the discharge at time of greatest need which measures their usefulness and value to farmers along their banks. A river which carries a torrent in December but is a bed of dry sand in July is of little value to irrigators if left as nature made it. There are hundreds of such streams in the West. They wind their lonesome courses through lands of unsurpassed fertility, where the climate is salubrious and healthful, and where only a perennial supply of moisture is needed to secure the growth of products of great diversity and value. On some the flood period comes a month too soon; on others months too late. The first objection applies to nearly all the rivers in the northern half of the irrigated region; the second to those in the southern half.

The important function of reservoirs is to bring the total supply into agreement with farmers' needs, in order that the water may be more completely utilized. The farther the natural flow falls short of accomplishing this the more important are reservoirs and the greater the necessity for their construction.

We need to know more about the quantity of water used in irrigating different crops and of the time when it should be applied to secure the largest yield. Definite information regarding both these matters must be secured before we can rightly estimate the value of an acre-foot of stored water, or the benefits of service which reservoirs can be made to render farmers and the amount of money which can be profitably expended in their construction.

The few investigations made have embraced only a relatively limited field, but they have brought such uniform and significant results as to make it certain that the extension and systematic prosecution of this investigation is a matter of great public importance.

The first irrigators depended wholly upon the natural flow of streams; they furnished the cheapest and most available water supply; but as ditches have multiplied and the reclaimed area has been extended and the demand on this supply increased, it has been ascertained that in order to utilize our resources and give to irrigated agriculture that security which it should possess the flow of these streams must be equalized and governed by the construction, where possible, of a comprehensive system of storage works.

The experience of Western farmers while irrigation is yet in its infancy and many rivers as yet untouched has demonstrated that on

the majority of streams which have a perennial flow storage will increase the area which can be farmed from two to five times. On streams where high water does not come during the irrigation season, or which run dry in summer, reservoirs are as indispensable as ditches or plows in the utilization of the water supply and bringing crops to maturity. The longer irrigation is practiced in a particular district and the more diversified its products the greater is the need of reservoirs and the more important the service they will render in increasing the stability and value of the irrigated farm.

That our appreciation of the need and value of reservoirs is destined to increase with the growing use of streams can scarcely be doubted. That has been the evolution in every other irrigated land, and there is nothing in the nature of things to indicate that this country is to prove an exception. The great number of tanks and the immense areas they reclaim in India, the massive and costly dams of Spain and Mexico, alike with the recent governmental construction of such works in Australia and Egypt, show that they are an essential feature of every complete irrigation system. Ghoulbourn Dam, recently built in the Province of Victoria, Australia, cost $700,000.

The demand of crops for the moisture needed in their growth varies but little from year to year, but the flow of the streams which supply this to the irrigator fluctuates widely. It is influenced by every passing cloud, and almost as much by the intensity of the summer's sun as by the depth of the winter's snow. The use of streams as nature made them is therefore attended with a waste and uncertainty which is not generally appreciated and which can scarcely be realized by those not familiar with the vicissitudes of irrigated agriculture. Irrigation has often been designated as an insurance against drought. In a large measure this is true; on many streams absolutely so; but like many other partial truths it depends on the kind of irrigation practiced and the character of the stream from which the irrigator takes his water supply as to whether or not this insurance is reliable.

In June, 1896, the users of water from the South Platte River below Denver, Colo., had reason to believe that something was lacking in their guaranty against drought. On the 1st the river carried 297 second-feet; on the 8th it had dropped to 53 second-feet. Both discharges were below its normal flow at that season of the year. All of the larger volume was needed; when the supply shrank to one-fifth of this it meant many empty ditches and parched fields. In like manner the irrigators on the Laramie River in Wyoming, who, on May 30 of the same year, had 2,000 second-feet to distribute and ten days later only 500, were led to believe that the uncertainty of rivers is almost as great as that of clouds.

At the beginning of the week the supply was greater than everybody could possibly use and at its close there was not water enough to fill the canal of one appropriator. These fluctuations are not exceptional. In the same year the Big Thompson River, a stream fully appropriated, carried on May 30, when the demand for water was limited, 911 second-feet; on June 30, when the demand was greatest, it had only 180 second-feet. In the same year St. Vrain Creek carried on May 30 573 second-feet; on June 1, or two days later, 373 second-feet, and on June 30 195 second-feet. In the same year the discharge of Boulder Creek was on June 1 466 second-feet, on July 1 141 second-feet, or the available volume at the time irrigation was beginning was more than three times the supply when the need was greatest.

The difference in the water supply for the different months of the

irrigation season has much to do with the present character of irrigated agriculture and with the acreage which is being farmed. It takes far less water to irrigate an acre of garden than it does a like area of native hay and the value of its product is far greater, but with the first water must be had when needed. The time of the application with the second is not important. The moisture required by an acre of wheat will irrigate an orchard ten times as large, but the first can be brought to maturity along a stream which goes dry in August. The last must have water the season through. An acre of oats requires many times as much water as an acre of corn or potatoes, but oats can be irrigated while streams are high; corn and potatoes require water when they are low. Orchards, gardens, alfalfa, and root crops all take less water than small grain, but they need it later in the season, and the ability of the irrigators of the Northwest to extend the area devoted to their cultivation will largely depend on the construction of reservoirs to augment the late water supply.

RESERVOIRS AS AN AID IN DISTRIBUTING WATER TO CROPS.

The problems of the northern and southern halves of the irrigated region are not the same. The character of the service which reservoirs will render to farmers is modified by climatic and other conditions to such a degree as to make a separate discussion of their influence on the agricultural growth of the two sections desirable.

To illustrate what is meant by the foregoing statement it may be stated that January is a wet month in California, but a dry one in Kansas and Montana. April is a dry month in Arizona and New Mexico; a wet month in much of California, Colorado, Utah, and Dakota. May is a dry month in California, New Mexico, and Arizona; a wet month in Colorado, Kansas, Dakota, Wyoming, and Montana. July is a very dry month in Utah, a very wet one in New Mexico.

This exact reversal of conditions, so far as moisture is concerned, in the irrigation months affects in a marked degree the distribution of water to crops and the relation of reservoirs to this question, and as this follows in a general way geographic lines, it simplifies the discussion of reservoir problems to divide the presentation of the influence of storage in the same manner.

(The terms "wet" and "dry" refer to the proportionate part of the annual rainfall and not to the absolute amount.)

IN THE NORTHERN HALF OF THE IRRIGATED REGION.

The fact that large volumes of water run to waste in the spring and early summer, while many fields are parched and thousands of acres of crops injured for lack of it in the last half of the season, is a matter of general observation and experience throughout a large part of the northern half of the irrigated region; but our information as to the details of the causes of this waste and the character of the remedy is largely confined to the investigations of the State engineers of Colorado, Wyoming, Utah, and Idaho and the agricultural experiment stations in the three first-named States.

The published measurements of the duty of water made by the Colorado and Wyoming experiment stations show (see Appendix) that if we exclude the irrigation of native hay, and consider only cultivated crops, but little water is required in irrigation before June 1; that July 1 is about the dividing date between the two halves of the irri-

gating season, the demand for water after that time being as great as before it. Out of 24 published observations of the time when water was used and measurements of the volume applied to crops, there were only three instances in which water was used in May, and no case where any was required in April.

The published reports of the Utah Experiment Station do not give the details as to the dates when water was used, but the diagrams of results all begin with June 1, which would seem to indicate that the use of water in either April or May was unimportant.

The investigations into the irrigation of crops by Professor Carpenter, of the Colorado Experiment Station, led him to the conclusion that on the Poudre River the need of water in irrigation after August 1 was greater than before June 1. This conclusion was reached several years ago, and as the tendency toward an increased use of water during the latter part of the season has been increasing continuously since that time, its correctness is more certain to-day than when announced.

The State engineer of Idaho, in his report for 1896, discusses the relative requirements of crops during the different months of the growing period and gives as his conclusion the following table of percentages:

	Per cent.
May	15
June	30
July	30
August	15
September	10
Total	100

The investigations of the State engineer of Wyoming have covered a period of ten years. Results are summarized in the report of that office for 1898, from which the following extract is taken:

In 1898 the study of the duty of water, which had been interrupted for several years, was resumed. One of the objects of this investigation is to determine the relation between the needs of crops during the different months of the irrigation season and the volume of stream discharges during those months. Records of the quantity used on three different farms in widely separated sections of the State were secured. One of these was interrupted by an accident, but this did not impair its value for the purposes of this discussion. In each case the farmers were requested to begin using water as soon as they thought it would do any good, and to use as much as they thought beneficial; in other words, to irrigate just as they would if no record was being kept. In neither instance was an acre of land irrigated or a drop of water used in April or May. Reports from a half dozen canals also state that irrigation this year did not begin until June. In all the records kept by the office in this and previous years we have not a single instance where cultivated crops were irrigated before June 1. The inference seems fair, therefore, that the greater part of the water supply of our streams during the months of April and May runs to waste. This is confirmed by the stream gaugings at Uva, on the Laramie, and by our general observations.

The total May discharge on Clear Creek in 1897 was 20,295 acre-feet, or more than the aggregate of July, August, and September combined. In 1898 it was about equal to that of the last half of the season, while more water ran to waste in June than was used during the whole season. From these various facts we draw the following conclusions:

(1) That irrigation based on the natural flow is governed by the discharge of the last half of the season, and that the limit of such irrigation has now been reached.

(2) That more water runs to waste in May than is used after July 1, and the loss in May and June is greater than the volume used during the entire year.

(3) That for seven months, from October 1 to May 1, no water is used in irrigation.

(4) That, notwithstanding the need of more water and the facilities already provided for its distribution and beneficial use, more than three-fourths of the entire supply runs to waste and will continue to do so until some provision is made to increase the late water supply by storage.

Not only does there seem to be an agreement between the records and the conclusions of observers that crops need more water after

July 1 than before that date, but that the demand for late irrigation is increasing.

Character of the water supply in the northern half of the irrigated region.—Let us now consider how nearly the flow of the streams of this region conforms to the needs of water users.

The report of the Wyoming State engineer for 1898 contains a table giving the acre-feet of water carried by six important irrigation streams for each month during the irrigation period, and another table giving the date and highest and lowest discharge. Both are given below:

Total monthly and seasonal flow, in acre-feet, of the rivers on which gauging stations were maintained for the years 1897 and 1898.

Stream.	Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Total.
Shoshone River	1897	....	490,000	308,504	143,471	42,669	21,384	......	1,006,028
Do	1898	44,609	240,637	435,323	233,759	43,000	19,424	......	1,016,752
Clear Creek	1897	....	20,295	16,602	5,503	3,332	1,960	2,026	49,718
Do	1898	....	....	32,160	11,780	2,948	1,318	2,087	50,093
North Platte River	1897	253,166	790,670	495,363	102,369	47,426	31,360	......	1,720,354
Do	1898	102,940	385,037	333,193	67,725	33,329	26,126	......	948,350
Laramie River (Uva)	1897	8,639	117,968	91,634	19,366	6,944	3,437	......	247,988
Do	1898	9,753	24,455	55,385	6,047	19	00	00	95,659
Laramie River (Woods)	1897	40,729	76,208	64,273	2,527	7,245	699	......	191,681
Do	1898	4,762	23,919	37,885	1,740	01	00	00	68,337
Green River	1897	118,764	559,849	446,013	177,048	103,880	50,738	......	1,456,292
Do	1898	162,728	255,742	522,823	278,336	92,167	56,422	46,132	1,414,350
Blacks Fork River	1897	....	243,782	77,374	20,453	8,780	7,231	......	357,620
Do	1898	99,624	105,989	101,277	25,887	6,572	356	7,940	347,645
Total	......	....	3,334,551	3,017,800	1,096,011	402,308	219,655	......	....

Dates of maximum and minimum discharges in 1897 and 1898, with the volume of such discharges in cubic feet per second.

Name of stream.	Year.	Maximum discharge.		Minimum discharge.	
		Date.	Volume.	Date.	Volume.
Shoshone River	1897	May 30	10,100	Sept. —	360
Do	1898	May 28	14,710	Sept. 28	20
North Platte River	1897	May 27	20,000	Sept. 16	500
Do	1898	....do ...	16,570	Sept. 12	420
Laramie River (Woods)	1897	May 25	3,410	Sept. 17	44
Do	1898	May 26	1,545	Aug. —	....
Laramie River (Uva)	1897	May 27	2,616	Sept. 15	7
Do	1898	May 28	1,182	Aug. —	....
Green River	1897	May 23	18,250	Sept. 17	800
Do	1898	June 27	15,100	Sept. 29	670
Blacks Fork River	1897	May 24	6,560	Sept. 1	33
Do	1898	Apr. 10	2,495	Sept. —	....
Clear Creek	1897	June 1	665	Sept. —	33
Do	1898	May 29	1,053	Aug. 29	17

Comparing these measurements of the supply with the results of investigations into farmers' needs, we find that the April supply at present does little or no good; that nearly all the water in May runs to waste and will continue to do so until stored; that the April volume, which is not needed, is greater than the August supply, which is insufficient; that the May discharge is more than double that of July, August, and September combined. When, therefore, all the late flow of these rivers has been used, there will still be water enough going to waste in April and May to double the area under cultivation.

These are not exceptional conditions. They prevail in other States, as is shown by the succeeding table.

The mean discharge in cubic feet per second of streams used in irrigation, from the Report of the Colorado State Engineer for 1896.

Name of stream.	May.	June.	July.	Aug.	Sept.
South Platte	502	281	233	189	250
Big Thompson	218	285	225	144	119
St. Vrain (1895)	....	1,040	680	488	125
St. Vrain (1896)	229	320	212	154	129
Boulder Creek	240	264	150	88	73
Arkansas River	1,097	895	633	489	309
Rio Grande River	2,374	821	403	261	477
San Juan River	1,635	444	256	189	309
Piedra River	1,048	229	111	59	347
Animas River	2,326	875	349	199	1,004
Dolores River	952	263	130	38	195
San Miguel River	770	349	157	65	176
Uncompahgre River	1,010	519	126	38	148

The situation which now confronts Western irrigators is, therefore, not a lack of water, but the prevention of its escape before the time arrives for its beneficial use. In other words, the holding back of the water which now runs to waste in April and May, and turning it over to irrigators in July and August. Doing this would not only save many thousands of acres which now are injured or destroyed by drought, but would so extend the reclaimed area as to absorb in direct irrigation much of the water supply which now runs to waste in June. The important question is how great a percentage of the total flow will have to be impounded in reservoirs to enable farmers to utilize the entire water supply. A definite answer to that can not now be given, until there has been further study of the needs of different crops.

That the practical value of reservoirs is as great as their theoretical importance has been demonstrated wherever they have been built. The potato crop of Greeley, Colo., is almost as widely known and widely distributed as the orange crop of California. The greater part of this crop receives its last irrigation from reservoirs, the entire flow of the river, at the time when water is needed for this purpose, not being equal to the demand of earlier appropriators elsewhere. Its present extent is therefore due to the reservoirs already built, and its further increase will be governed by their extension.

In 1898 the Laramie River was lower than ever before. For two months its bed in places was dry. If there had been no reserve supply all the crops which required irrigation after July 1 would have been a total loss. Of these there were 16,000 acres under a single canal. Not a drop of water entered this ditch after June 15, because there was none to be had, and the only thing which saved the farmers under it from a catastrophe was the building and filling of a reservoir the previous year. The value of the stored water in this instance was like that which puts out a fire—equal to whatever was saved by its use.

IN THE SOUTHERN PART OF THE IRRIGATED REGION.

The farther south we go the longer is the irrigation period. It begins earlier and ends later. In fact, there are sections where the use of water is continuous. In most of the regions where this is true, the variation in the precipitation and water supply for the different months is greater than it is in the sections we have just been discussing. Storage, instead of being used to increase the acreage farmed, becomes a necessity to the profitable farming of a single acre.

In the Pecos Valley of New Mexico irrigation begins in March, when streams are low and when rains do not fall. The ground needs irrigation before it is plowed, and frequently after the seeds are planted, to

make them germinate. Before the use of water in the north begins at all the demand for it in this section is excessive and imperative. If the flood season of the Pecos River agreed as to time with that of the Platte or Arkansas, storage might be dispensed with; but instead of the flood flow coming as early, or earlier, it does not arrive until the rainy period, in June and July—altogether too late to be of itself of service to irrigators. Storage reservoirs, to hold it over for the succeeding spring, are therefore as necessary as canals in making use of this stream by farmers.

In no part of the United States has irrigation wrought a greater transformation or created greater increase in values than in southern California. In much of this region reservoirs are not merely an instrument for the extension of the reclaimed area—they are an absolute necessity. The streams are intermittent in character; instead of having a perennial flow they are torrential in winter, but in summer and fall, when most needed for irrigation, are almost dry. The Sweetwater River, the site of the famous Sweetwater Dam, is a typical stream. The winter storms would bring its volume up to from 500 to 1,000 cubic feet per second, to recede again in a short time to 10 or 20 cubic feet per second. After the close of the rainy season in March it would shrink to 1 or 2 cubic feet per second, which sometimes ran through the year, but not always. A water supply of this character is of no use to irrigators. Without this reservoir the lands which this river has been made to reclaim would have remained practically worthless. By its construction many thousands of acres of sagebrush and cactus have been transformed into orange groves and gardens, and millions of dollars added to the taxable and productive wealth of the State and nation. Similar illustrations of the necessity and importance of reservoirs as a part of our irrigation system throughout the southern half of the irrigated region might be multiplied indefinitely.

RESERVOIRS AS A PROMOTER OF BETTER METHODS OF IRRIGATION.

Wherever reservoirs are built they do more than make it possible to utilize the floods which now run to waste. They are the most effective educator yet devised for making farmers realize the value of economy and skill in the application of water, and bringing them to practice both. The result of their construction has been therefore to improve methods and increase the yields and value of products from the acres cultivated.

Where farmers depend on the natural flow of streams they know that the months of abundance will be followed by months of scanty supply. The tendency to use more water than is beneficial while it can be had is therefore very strong, and the practice of doing this widespread. This is especially true of farmers having late priorities. They endeavor to guard against the coming drought by saturating the subsoil while water can be had.

Irrigation authorities now encourage this practice, because it tends to lessen the danger of total failure, but it is attended by two disadvantages and productive of one very decided evil.

The application of more water than is needed at any time is an injury to both the crop and to the land. Where the subsoil is porous it tends to wash out the soluble salts and diminish the fertility of the soil. Where the subsoil is impervious the land is often converted into a marsh and cultivation made impossible. Areas which have been subjected to this sort of irrigation are familiar to all those who have ever visited an irrigated region. The worst feature connected there-

with is the fact that the injury wrought is frequently suffered by others than those responsible therefor. The late appropriators generally live on the higher lands, and it is their attempts to utilize the subsoil of their fields as a reservoir which concentrates the alkali and creates the marshes on the farms of the earlier appropriators in the bottoms below them. The diagram which follows shows both the imperfect character of stream discharges and the abnormal use of water in irrigation which results therefrom.

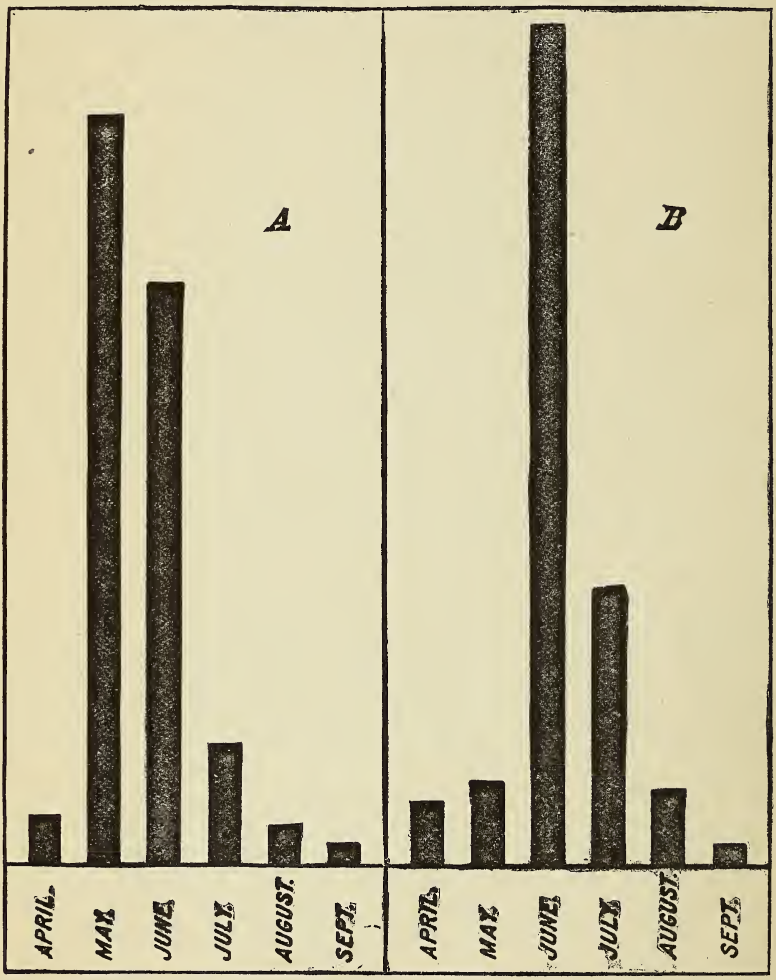


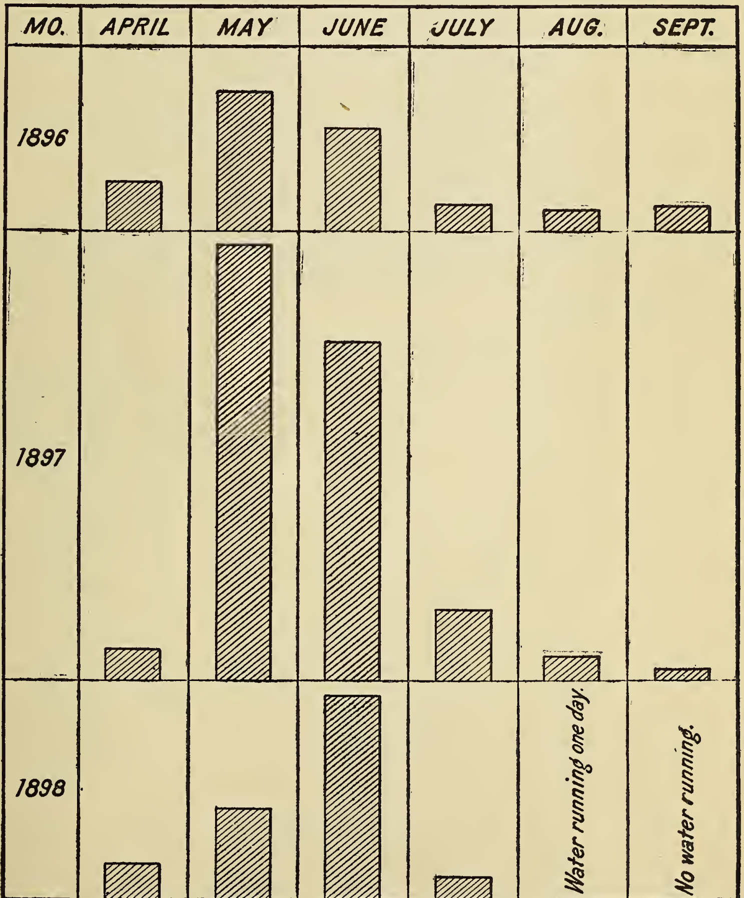
FIG. 1.—Diagram showing variation in the flow of streams and in the use of water in irrigation for the different months of the irrigation period, and the relation between the available supply and the needs of agriculture. *A*. Discharge of the Laramie River at Woods, Wyo. Scale, 1 inch equals 30,000 acre feet. *B*. Use of water, from measurements at Wheatland, Wyo.

The storage of flood waters would put an end to this wasteful and injurious practice by removing the cause. If an adequate supply for late irrigation were assured, farmers would practice economy in the first half of the season, as they now do in the second, because of the better results which it would secure. The methods which are employed in the

use of stored water teach economy, because the volume used is measured, and waste means a direct increase in cost to the irrigator. Where water is taken from the stream, its negligent or waseful distribution may cause loss to others; but the evils of this do not come home directly to the irrigator himself as they do when he takes water from a reservoir and is accountable for whatever he receives.

RESERVOIRS AS AN EQUALIZER OF STREAM FLOW.

The construction of reservoirs will benefit farmers by taking away the destructive character of the floods which now sometimes beat against the head gates of their ditches. It will also render the water supply more uniform and stable from year to year. The fact that rivers vary as widely in the volume they carry as does the depth of rainfall in humid regions is not generally appreciated. It is, nevertheless, the case. The variation in the amount of water carried in different years is great, and as we approach the complete utilization of the supply the holders of late priorities find that years of low water means to them years of failure. The following diagram showing the



1896	13,170	37,996	27,611	7,803	5,817	6,890
1897	8,639	117,968	91,634	19,366	6,944	3,437
1898	9,753	24,455	55,385	6,047	38	0

seasonal variation of a Western river illustrates this. A change in the June, 1897, discharge of 117,900 acre-feet to the 1898 discharge of 24,000 acre-feet means that much water was wasted the first season or a good many fields were dry the second, while the change from water enough to cover nearly 7,000 acres a foot deep in August, 1897, to only enough to cover 38 acres to that depth in 1898, shows that streams are as variable as clouds.

A comprehensive reservoir system will make it possible to hold back a part of the supply in years of abundance for use in subsequent seasons of drought. It will give added force to the tendency of irrigation to convert intermittent streams into perennial ones. Experience has shown that a large percentage of the water used in irrigation returns to the stream, to be again spread over fields below or to increase the flow of rivers during low water. The full benefits of this action can not, however, be secured so long as more than half of the water passes off unused in the spring. The increased diversion in ditches which would come from storage will proportionately augment the amount of return or seepage water added to the stream in July and August.

There is an imperative need of a careful study of this question, in order that the facts as to the volume of water absorbed and the percentage of the volume diverted, which returns may be ascertained, and its relation to interstate and international controversies over water rights, be understood and appreciated. That the storage of flood waters near the sources of streams is destined to increase their flow throughout their length, and thereby to mitigate interstate controversies over water rights, can scarcely be doubted.

The following table, showing the increase in rivers from return or seepage waters, is the result of careful measurements extending over many years. They are taken from the reports of the State engineers of Colorado and Wyoming and of the experiment station of the Colorado Agricultural College.

Return waters from irrigation.

Stream.	Original volume.	Gain from seepage.	Number of miles.
	Sec. feet.	*Sec. feet.*	
Poudre River	127.7	86.9	35
Do	68.7	98.9	38.6
Do	80.8	100.8	38.3
Do	97.6	84.6	38.7
Do	65	96.1	34.8
Do	62.9	101.6	38.6
Do	52.5	98.7	38.1
Do	99.2	82.3	38.1
Do	268	118.1	38.1
Do	66.5	164	38.1
South Platte River	45.7	217.1	98.2
Do	98.5	165.6	98.5
Do	114.6	275.3	149.2
Do	473	216.6	47.5
Do	124	254.8	99.7
Do	308.7	301.2	152.2
Do	123	510.1	152.2
Horse Creek	18.3	79.8	70
Do	5.9	17.5	70

The addition to a stream of a greater volume of water than it carried originally would seem to partake of the nature of the miracle of the loaves and fishes, but this is not the case. Nearly all of these measurements were made during the latter part of the irrigation season. The

large increase comes from the greater volume diverted when these rivers were high. The fact that a stream like the South Platte, carrying only 98 second-feet at the head, should gain in less than 100 miles from the seepage from irrigated fields nearly twice as much as it carried when it left the mountains, is significant of the benefits which are to come to irrigators farther down by the further extension of the reclaimed area above.

APPENDIX.

Date of irrigation and depth of water applied; investigations of duty of water, Colorado Experiment Station, 1893.

Place.	Crop.	Date irrigated.	Depth of water.	Total
			Feet.	*Feet.*
Plat E	Alfalfa	May 19, 28	.47	[illegible]
Do	do	July 6	.36	
Plats A, B	do	May 27–31	.51	1.01
Do	do	July 11–17	.50	
Plat D	Clover	May 28–29, 31, June 1	.54	1.14
Do	do	July 1–2, 3–4	.60	
Plat G	Wheat	June 1–4, 6–8, 10–11	.96	1.37
Do	do	July 6–9	.41	
Plat C	do	June 6–8	.55	.89
Do	do	July 10–11	*a* .34	
Plat F	Oats	June 11–14	1.02	1.70
Do	do	July 2–3	.56	
Do	do	July 17	*a* .12	

a Not fully irrigated owing to lack of water.

Acre-feet of water diverted by the Greeley No. 2 Canal in the different months of the irrigation season.

Month.	1890.	1891.	1892.
April			741
May	3,582	7,746	7,759
June	20,850	15,050	22,216
July	12,426	10,932	17,266
August	6,372	2,848	2,099
September	1,324	1,334	175
October		296	
	44,554	38,206	50,250

Estimate of Prof. L. G. Carpenter of the quantity of water that would be required to supply district No. 3 during the season.

From—	Cubic feet per second.	From—	Cubic feet per second.
March 1 to April 15	250	July 10 to August 1	1,800
April 15 to May 10	500	August 1 to September 1	1,200
May 10 to June 1	1,000	September 1 to October 1	750
June 1 to June 10	1,800	October 1 to November 1	350
June 10 to July 10	2,500	November 1 to December 1	250

Dates of irrigation and depth of water applied. Investigations of duty of water, Wyoming Experiment Station, 1892.

Place.	Crop.	Date irrigated.	Depth of water.
			Inches.
Laramie experiment farm	Mixed		30.6
Wheatland experiment farm	Oats	June 20 to July 12	17.4
Laramie experiment farm	Sugar beets and rutabagas	June 16–17, Aug. 16, Sept. 22.	9.9
Do	Corn	July 20	4.0
Do	Cane and Dhoura	July 23	8.7
Do	Peas and beans	June 5	4.9
Do	Mixed		13.5

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